REFERENCE LOAD LINES AID IN ANALYSIS OF THE DOWNHOLE DYNAMOMETER PUMP CARD

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ABSTRACT

Pump cards have three load reference lines 1) Zero Load line, 2) Fluid Load line from Fluid Level, Fo, calculated using the pump intake pressure determined from an acoustic Fluid Level measurement, and 3) Maximum Fluid Load, Fo max, line calculated by setting the pump intake pressure equal to zero. Certain downhole pump problems can be recognized based on the location of the pump card loads with respect to the three load reference lines. When there is no apparent pump action the load value of the flat pump card can be used to determine if there is 1) a shallow rod part, 2) a deep rod part or traveling valve, TV, is stuck open, 3) Tubing is dry of well fluids, 4) the standing valve, SV, is stuck open or 5) the SV is stuck closed with no fluid is entering the pump. Typical pump card loads plot near zero load line on the down stroke and the loads plot near Fo from Fluid Level load line on the upstroke.

INTRODUCTION

Sucker rod lifted wells are routinely evaluated using dynamometer testing. During the 1960s, S.G. Gibbs[1] presented the wave equation model that is used to mathematically "wave down" the measured surface load and position to calculate precise and reliable downhole pump load and position. The ability to use a computer[2] to calculate the downhole load and position at the pump has become the basis of modern pump card diagnostic analysis and pump troubleshooting.

Current portable dynamometer instruments use high performance digital data acquisition systems to record dynamometer data for analysis of the sucker rod lift pumping system. The most widely used portable dynamometer acquisition system consists of a laptop computer, an analog to digital converter, and a load cell with accelerometer. The load cell uses a strain gauge circuit to accurately measure the load on the polished rod. The load cell can be of the horseshoe type, which is temporarily positioned around the polished rod between the carrier bar and the polished rod clamp, or can be a permanently mounted donut type load cell. Alternately, a polished rod transducer, PRT, of a special design is easily clamped directly onto the polished rod and is used to measure load indirectly by sensing the change in the polished rod diameter through out a stroke. Numerical integration of the accelerometer output is used to calculate polished rod velocity and position versus time. This polished rod load and position data is processed to plot the surface dynamometer card and waved down to calculate the pump dynamometer card.

The surface and pump dynamometer plots are used to analyze the operation of the sucker rod pumping system. The surface dynamometer card is the plot of measured polished rod load at the various positions throughout one complete stroke. The pump dynamometer card is the plot of the calculated load at various positions of pump-plunger and represents the load the pump-plunger applies to the bottom of the rod string during the stroke. The pump card represents the load and position of the pump-plunger as if a downhole dynamometer measurement[3] had been made by placing the load cell and the position indicator just above the pump-plunger. The purpose of the wave equation software is to convert the loads and position measured at the polished rod to the actual load and position of the pump-plunger during the pump stroke. Identifying how the pump is performing and analyzing downhole problems is one of the primary uses of the pump dynamometer plot.

Three load reference lines are important aids in the process of analyzing the pump card and identifying particular downhole problems. **Fig. 1** displays a pump card annotated with these three load reference lines: 1) Zero Load line, 2) Fluid Load, Fo, from Fluid Level, and 3) Maximum Fluid Load, Fo max.

The pump card for normal pump operation is plotted with the loads near the zero load line during the major part of the down stroke and is plotted with the loads near the Fo from Fluid Level load line during the major portion of the upstroke. Since abnormal pump operation causes deviation from these characteristics it is very important that the loads corresponding to the reference lines be computed accurately. Correct positioning of Fo from Fluid Level and

Fo max load lines depends on accurate: 1) pump intake pressure, 2) measurement of the tubing pressure, 3) measurement of change in tubing pressure, 4) true vertical depth to the pump, 5) tubing fluid gradient, 6) damping factor, 7) wellbore information and 8) plunger diameter. Inaccurate input data or extra unaccounted friction is the usual reason the top of the pump card plots above the Fo from Fluid Level load line and/or the bottom plots below the zero load line on the down stroke.

When a rod part occurs or when either the traveling or standing valve is stuck open or stuck closed, then the resulting flat pump card represents a constant load being applied to the rods throughout the stroke. The position of the wave equation calculated flat line pump card relative to these three pump card load reference lines can be used as an aid by the dynamometer analyst to identify the correct downhole condition and to properly troubleshoot the well's downhole problem.

FLUID LOADS EXERTED BY THE PUMP

The fluid load, Fo, is directly related to the differential pressure acting across the area of the pump plunger. The load the pump applies to the rod string on the up stroke is the result of the tubing pressure plus the pressure from the tubing column fluids being applied to the top of the closed TV in the plunger minus the pump intake pressure from the inflow of the well's fluids into the pump barrel applied to the bottom of the closed TV inside the plunger. The fluid load, Fo, is equal to this differential pressure (discharge – intake) acting on the area of the plunger, Ap.

Fo = (Pdis - Pintk)*Ap ……………………………………………….. (1)

On the upstroke the full fluid load is applied to the rods by the pump when the traveling valve, TV, is closed with wellbore fluids flowing into the pump barrel through the open standing valve, SV. The fluid load on the upstroke corresponds to the height of the pump card above the zero load line. During the stroke, from the time when the TV ball goes on the seat until the TV ball comes off the seat, some differential pressure is acting across the closed TV and fluid load is applied to the rods due to the closed TV completing a pressure seal between the plunger and the barrel. When the TV ball is off the seat there is little or no differential pressure acting across the TV, therefore no load is applied to the rods by the pump. During the downstroke, with the TV open and SV closed the pump card loads should be near the Zero Load Reference line. Near-Zero load is typically applied to the rods by the pump on the downstroke as the fluid in the pump is displaced into the tubing through the open traveling valve, TV, while the full tubing pressure acts to keep the standing valve, SV, closed. During the upstroke, when the SV is open and the TV is closed, the top of the pump card (Fo-up) should be near Fo from the Fluid Level Load reference line and on the downstroke when the TV is open and the SV is closed the pump card Fo should be near the Zero Load reference line.

EXAMPLE PUMP CARD

The pump card shown in **Fig. 2** is identified as "Downhole Dynamometer Testing Gassy Well w/separator on Amerada Hess Corporation SSAU 4115 well" as a part of a Sandia Dynamometer Project[3], this pump card's load and position were acquired using a Glen Albert Down Hole Load Cell installed downhole directly above the pump. In **Fig. 2** point A identifies the beginning of the upstroke, from A to B the pump plunger remains stationary while the rods gradually stretch until the fluid load, Fo, is transferred from the tubing (standing valve) to the stretched rods (traveling valve). At point B the standing valve opens due pressure inside the pump barrel being less than the well pressure at the pump intake. At point B the force exerted by the stretched rods balances the Fo and the plunger begins to move upward in the barrel of the pump. During the upstroke from B to C the stretched rods carry the fluid load as the rods and plunger move upward on the upstroke. Point C is the top of the plunger upstroke and where the standing valve ball goes on seat. After point C as the plunger compresses the fluid inside the pump barrel, the load is being transferred from the rods to the closed SV attached to the tubing. At point D the TV ball comes off the seat as the pressure inside the pump barrel exceeds the discharge pressure at the bottom of the tubing; the plunger is completely unloaded slides through the fluid in the barrel. During the downstroke both plunger and polished rod move nearly together due to the absence of load at the bottom of the rod string. This process is repeated for each additional stroke.

From points B to C the rods carry the fluid load during the upstroke. The average of the pump card load during the upstroke is defined as FoUp. From points D to A the tubing carries the fluid load on the down stroke. The average pump card load during the downstroke is defined as FoDn...

For low viscosity well fluids the friction force between barrel and plunger is usually small and the pressure drop across the standing valve is usually small, so that the pressure inside the pump barrel is close to the pump intake pressure. On the downstroke the load the pump applies to the rods is near zero, because the pressure inside the pump barrel is almost equal to the pump discharge pressure. For low viscosity fluids the friction force between barrel and plunger and the force due to fluids moving through traveling valve are usually small. On the downstroke, FoDn represents the average pump card loads and this line should be near zero load reference line. On the upstroke, FoUp represents the average pump card loads and this line should be near Fo from Fluid Level load reference line. When the well is produced at is maximum potential with low pump intake pressure, and then the FoUp load should be near the Fo max load reference line.

DYNAMOMETER LOAD CELLS

In general three types of load cells transducers are used to acquire dynamometer data 1) Horseshoe load cell, 2) Donut Load Cell, and 3) Polished Rod Load Cell. The most accurate dynamometer measurements are obtained using a calibrated strain gauge load cell, which directly measures the load on the polished rod. Using an accelerometer is the preferred method to determine the polished rod position. The instantaneous acceleration is measured accurately, and then Polished rod velocity (inches per second) is computed by integration of acceleration with respect to time, and polished rod position is computed as the integral of velocity with respect to time. Accurate polished rod position and velocity describe the exact motion during a pumping cycle. The position determined by using string box potentiometers attached to the carrier bar or by inclinometers attached to the walking beam tends to have insufficient resolution at the top and bottom of the stroke where the polished rod comes to a temporary stop. The following 3 paragraphs briefly discuss each type of load cell:

Horseshoe Load Cell Transducers are used to very accurately measure polished rod load. Strain gauges are mounted onto load supporting members and the horseshoe load cell calibrated to yield a measured load accuracy of 0.5% of rated load or better. Offloading or side loading due to the carrier bar being tilted does not affect the accuracy of the load measurement due to the averaging effect of the multiple gages. The horseshoe transducer is installed between the pumping unit carrier bar and the permanent polished rod clamp. Changing the spacing of the pump is one disadvantage of using some types of horse load cell. If the transducer is 3" high, then the pump plunger is raised 3 inches when positioning the horseshoe load cell into the space between the carrier bar and the permanent polished rod clamp. This problem is not an issue if a spacer assembly consisting of a spool and 2 washers are permanently installed between the polished rod clamp and carrier bar, then the plunger is raised only 0.15 inch, when the horseshoe load cell is installed into the spacer assembly.

Permanently Mounted Donut Load Cells is a cylindrical (donut) shaped and usually has strain gauge rosettes located at equal distances around cylindrical body. The donut load cell is permanently mounted over the polished rod between the carrier bar and the polished rod clamp. Position of the walking beam is often determined through some type transducers where the voltage signal is proportional to the angle swept through by the walking beam. Generally these installations are used in conjunction with pump off controllers or as field end-elements in SCADA systems. In conjunction with a separate position transducer, such as a clamp-on accelerometer, the donut load cell can be used to acquire dynamometer data using a portable dynamometer system.

Polished Rod Transducer, PRT, is used to acquire data that allows the calculation of load and position and determination of a surface dynamometer card. The polished rod dynamometer data is sufficiently accurate for most analysis. The position of the plunger in the pump barrel is not changed by the installation of the PRT, as occurs in some horseshoe dynamometer installations. For this reason, the polished rod transducer analysis may be more representative of actual well performance than an analysis using a horseshoe transducer that raises the rods and plunger in the pump. A PRT measures either the change in diameter or the elongation of the polished rod and converts the corresponding strain to the change in load on the polished rod during the stroke. The extremely small diameter changes of the polished rod are detected using sensitive solid-state strain gauges. Position of the polished rod may be obtained from double integration of acceleration, or measured independently with a position sensor or approximated from pumping unit geometry and a time reference signal that flags the bottom of the stroke. The change in load for a pump stroke and the calculated positions from the acceleration data are used to generate a surface dynamometer card. Software calculates a pump card using the wave equation solution using the acquired relative load values and the polished rod position data. The relative loads of the surface and downhole cards are calibrated by software using the principle that the average load the pump applies to the rod string during the downstroke when the traveling valve is open should equal zero and the bottom of the pump card should rest near the zero load line. The surface card, which contains both positive and negative relative load values, is adjusted by the same offset used to set the average of the down stroke pump card loads to zero. This method forces the bottom of all pump cards from the PRT to set on the Zero Load Reference Line.

When there is no apparent pump action the load value of the flat pump card, obtained with a PRT load sensor, will always be near the zero load reference line and cannot be used to correctly diagnose the problem that resulted in the flat pump card. A horseshoe or donut load cell transducer should be used to repeat the dynamometer test when a flat pump card is displayed in order to precisely determine the polished rod load. Then the pump card load can be used to diagnose and troubleshoot the problem based on comparison to the pump card load reference lines.

PUMP PROBLEMS DIAGNOSED FROM REFERENCE LOADS AND DYNAMOMETER DATA

The previous sections in this paper describe dynamometer load cells and describe the reference loads of a pump dynamometer card. Acquiring accurate dynamometer data representative of the well's normal operating conditions requires the operator to take care when he acquires data. A sucker rod pump operated in a continuous mode is constantly lifting fluids to the surface, while maintaining steady state conditions with a constant producing bottom hole pressure and continuous inflow into the wellbore. When there is no pump action and no fluid is being lifted to the surface the corresponding pump dynamometer displays a nearly flat line plotted at some load level. The following sections discuss how to identify a particular pump problem that corresponds to a specific flat load value by comparing the indicated load to the reference loads.

STANDING VALVE STUCK OPEN

A standing valve stuck open occurs when trash, sand, scale, asphaltene, or some other foreign material that lodged in the standing valve assembly causes the SV ball to stick in the cage and/or rest off the seat of the SV. The polished rod load versus time in **Fig. 3** displays dynamometer data acquired while the pumping equipment was operating. Notice the "?" symbol placed on the figure identifies the time period when the polished rod load remained high for several strokes... A possible explanation is that the fluid load remained on the closed TV and the TV loads were not transferred to the SV during the down stroke for strokes 29-34, the SV polished rod loads on the down stroke appear to be missing. The SV remained stuck open during this time period, but the SV returned to normal operation beginning at stroke 35 and for the rest of the data collected. Dynamometer surface and pump cards for stroke 30 are displayed in **Fig. 4**. During stroke 30 the SV ball is stuck off the SV seat and stroke number 30 displays the resulting flat load line showing no pump action is occurring. The left side of the figure shows that if a PRT dynamometer was used to acquire the data, then the flat load line would rest on the zero load line, which is incorrect. The right side of Figure 4 shows the dynamometer cards when data is acquired with a horseshoe load cell. In this case the flat load pump card plots correctly at or near the Fo From fluid Level Load reference line. When the SV ball is continually stuck off the SV seat, then the fluid load is constantly being applied to the rods by the closed TV and none of the fluid load can be transferred from the plunger back onto the tubing. If a SV stuck open condition occurs, the pump card loads plot as a flat line on or near the "Fo From Fluid Level" load reference line provided a fluid level measurement has been completed.

TRAVELING VALVE STUCK OPEN

A traveling valve stuck open occurs when trash, sand, scale, asphaltene, or some other foreign material that lodged in the traveling valve assembly causes the TV ball to stick in the cage and/or rest off the seat. In **Fig. 5** stroke number 11 shows normal pump action with the pump card setting near the zero load line during the downstroke and plotting near the Fo from the fluid level load reference line during the upstroke. During stroke 12 the TV ball stuck off the TV seat and stroke number 13 displays a flat load line showing no pump action. Notice for the surface dynamometer card number 13 trace after the TV stuck open that both the standing and traveling valves measured test loads are located at the theoretical weight of the rods in tubing fluid (standing valve test load value). When the TV ball is continually stuck off the TV seat, then no load from the plunger can be applied to the rod string by the pump. If a traveling valve stuck open condition occurs, then the pump card loads plot as a flat line on or near the zero load reference line.

RODS PARTED AT PUMP

The dynamometer surface and pump cards for deep rod part is shown in Fig**. 6.** This failure of the rods occurs when the sucker rod string separates from the plunger or breaks a few rods above the pump. The pull rod in the pump could unscrew and the appearance of the pump card would be the same. The pump is no longer attached to the rod string, and the plunger cannot apply any fluid load to the sucker rod string. When a deep rod part occurs, the pump card loads plot as a flat line on or near the zero load reference line.

The surface dynamometer cards for parted sucker rods generally plot as an overtravel card, where the pump stroke is longer than the surface polished rod stroke. A surface dynamometer card is classified an overtravel card when the surface stroke is shorter than the pump stroke and the surface dynamometer card plot slopes downward and to the right. Since there is no loss of downhole plunger stroke due to the rods stretching to transfer the fluid load from the standing valve (tubing) onto the traveling valve (sucker rod string). Overtravel occurs because the plunger stroke is lengthened due to the dynamic effect from pumping faster than zero strokes per minute. The measured surface dynamometer loads should plot near the computed Wrf reference line, because only the weight of rods in fluid is being applied to the surface load cell without any load being applied to the rods by the pump.

One symptom of the rod part is that no fluid is produced to the surface. The pump and surface dynamometer cards for the condition where the traveling valve is stuck open has a very similar appearance to a deep rod part. In some cases trash in the pump keeps the traveling valve ball from going on seat or the trash sticks the traveling valve open. If a flat pump card on the zero load line is the observed condition, then a deep rod part or traveling valve stuck open would be the diagnosis. In some cases lowering the plunger and tagging lightly on the down stroke can knock any trash out of the pump. Tagging the pump and regaining pump action can be used to prevent a misdiagnosis of a deep rod part. If pump action is regained, then the plunger should be spaced out properly since if left tagging long term damage to the pumping system will occur due to the constant unnecessary impact loads.

RODS PARTED HIGH ABOVE THE PUMP

The rod string data and dynamometer cards corresponding to a shallow rod part are shown in **Fig. 7.** On the left graph the flat pump card plots below the Zero Load Line by 3536 Lbs which is equal to the weight of the missing rods.

It is possible to determine the depth at which the rod part occurred by adjusting the rod description data (shown at the top of the figure) that is used in the calculations. When the length of the remaining rod string is corrected by adjusting the lengths of the bottom tapers then the computed flat pump card load aligns correctly with the zero reference line, as shown in the graph on the right. This adjustment is done by removing the missing 275 feet of 1.5 weight bars and removing the missing 925 feet of the 2350 feet of 7/8 inch rods. This corrects the rod string length and weight in the data file to match the failed rod string length connected to the polished rod clamp now resting on the horse shoe load cell. The recalculated wave down flat pump card now correctly plots near the zero load line indicating that the rods parted at about 925+275= 1200 feet from the bottom. The pump is no longer attached to the rod string, and pump cannot apply any fluid load to the sucker rod string. By adjusting the rod string length the flat pump card loads will move up toward the zero load line, when the sucker rod string lengths are correct and the pump card plots as a flat line near the zero load line. When a shallow rod part occurs, the pump card loads plot as a flat line below the zero load reference line by the missing weight of rods in fluid that are no longer attached to the rod string.

FLOW INTO PUMP BLOCKED

Fig. 8 shows two different conditions only a few strokes apart for the same well, where the surface and pump dynamometer cards on the left side show the loads when pumping first begins after the well has been shut down for a period of time. On the right side the set of surface and pump dynamometer cards shows the 4^{th} stroke after beginning to pump the well. On the first stroke FoUp matches Fo from the Fluid Level, which means during the upstroke the pressure inside the pump barrel is approximately equal to the pressure in the wellbore near the pump intake. On the fourth stroke the pump card becomes nearly a flat line and FoUp matches FoMax, which means during the upstroke the pressure inside the pump barrel is now close to zero. The fluid level or pump intake pressure did not change during the elapsed time from stroke 1 to stroke 4. The pressure inside the pump barrel dropped to 0 by the forth stroke, because flow of fluids into the pump intake is choked off. Flow into the pump is blocked or choked off due to the intake being completely blocked off when trash, sand, scale, asphaltene, or some other foreign material... The same conditions often occur when the pump intake is set below the bottom of the perforations and sand fill covers the intake to the pump. In some cases a sand filter or screen on the outside of the pump can become clogged with fines and choke the flow into the pump. In other wells when scale problems are an issue, a perforated sub or screened intake can become completely sealed off due to scale. When flow of fluids into the pump is blocked, then the pump card loads plot as a flat line on or near the FoMax load reference line...

TUBING DRY OR PARTIALLY DRY

Fig. 9 shows data acquired on two different wells where the tubing is primarily dry due to a deep hole in the tubing. For these two wells the annular fluid level is near the pump intake and the pump intake pressure is low. These pump cards are not quite flat load lines, because the pump, SV, and TV are operating properly. The fluid load (FoUp - FoDn) is much less than normal, because the pump is lifting only the differential pressure required to lift the fluid from the pump intake pressure out the hole in tubing and back out into the casing annulus. Normally the dynamometer would measure the dynamic forces for lifting the weight of rods in fluid, Wrf, plus the Fo applied to the rod by the pump. Both examples show the surface dynamometer measures too high a load due to measuring the dynamic load of the weight of rods in air, Wra, plus a portion of the rod string in fluid below the hole, Wrf, and very little fluid load applied to rods by a properly functioning pump.

Wrf = Wra – 0.128GWra ……………………………………………………….………. (2)

Eq. 2 is the relationship published[6] in APIR P11L that relates Wra to Wrf, where -0.128GWra presents the buoyancy force applied to the rods by the volume of tubing fluid displaced by the sucker rod string. **Eq. 2** should not be used for rod strings having fiberglass rods because 0.128 is the ratio of water density to steel density. The wave equation dynamically subtracts the Wrf from the measured surface dynamometer load. Since these two well's sucker rod string is not fully buoyed in tubing fluid the calculated FoDn is shifted upward off the zero load line by the missing buoyancy force. In both examples the dynamometer measured rod load is lighter that Wra and heavier than Wrf, because a portion of the rods above the hole are Wra with out buoyancy and below the hole the normal Wrf including buoyancy. When tubing is dry or partially filled with liquid the pump card plots as a flat line above the zero load reference line by the missing buoyancy force.

CONCLUSION

Five different flat fluid load pump cards having no pump action are identified and located with respect to the pump card basic load reference lines in **Fig. 10. Fig. 10** also shows the pump card for a normally operating pumping system. A flat pump card means that there is no pump action and the normal transfer of the fluid load back and forth from the SV and TV during the stroke is not occurring. The relative location of the flat pump card load can be used to identify and troubleshoot a problem in the well. When the pump card plots as a flat line the problem at the pump is likely to be one of these 6 problems: 1) the traveling valve could be stuck open, 2) a deep sucker rod string part occurs near the pump depth 3) the rods could be parted at a depth above the pump, 4) tubing could be dry, 5) the standing valve could be stuck open, or 6) flow from the well into the pump is restricted or blocked. Recognizing the conditions which cause these flat load lines to occur is a critical step in the analysis and troubleshooting of these downhole problems.

When the pump is performing without restriction to flow, fluid friction on the rods is in a normal range, fluid is being produced up the tubing to the surface, and a constant pump intake pressure is maintained, then a normal pump card should be displayed. The plot of the normal pump card should show the pump's fluid load on the down stroke near the zero load reference line and show the pump's fluid load on the up stroke near the fluid load reference line calculated using the pump intake pressure determined from a fluid level

Horse shoe and donut type of dynamometer load cells directly measure the polished rod load. When the polished rod load is directly measured and the wave equation calculated pump loads are flat, then the pump card loads values can be used to identify particular problems. When directly measured polished rod loads are acquired, the location of the calculated load values can be used to identify one of six specific down hole problems. Some types of dynamometer load cell do not directly measure the polished rod load, but calculate the surface loads by assuming pump card should set on the zero load line. These types of dynamometer load cells infer the surface loads using the weight of rods in fluid and adjust the measured change in load to be representative of the surface loads. If the surface loads from the PRT type of dynamometer are used to determine the pump loads, then the calculated pump card loads CANNOT be used to identify which of the 6 problems is causing the pump card to be flat. When this type of dynamometer is used, then the location of the calculated pump loads on the down stroke is always on the zero load line. If this type of dynamometer is used to acquire dynamometer data and pump card is flat, then the problem is difficult to diagnose. To be able to diagnose the downhole problem a dynamometer that directly measures the polished rod load should be used to re-acquire a set of dynamometer data at the well.

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Nomenclature

Fo = **Fluid Load Acting on the Plunger**
Pdis = **Pump Discharge Pressure**
Pintk = **Pump Intake Pressure**
Ap = **Plunger Area**
FoMax = **Max Fluid Load on the Plunger**
PRT = **Polished Rod Transducer**
FoUp = **Fluid Load on Up Stroke**
FoDn = **Fluid Load on Down Stroke**
Wrf = **Weight of Rods in Fluid**
Wra = **Weight of Rods in Air**
G = **Tubing Fluid Specific Gravity**

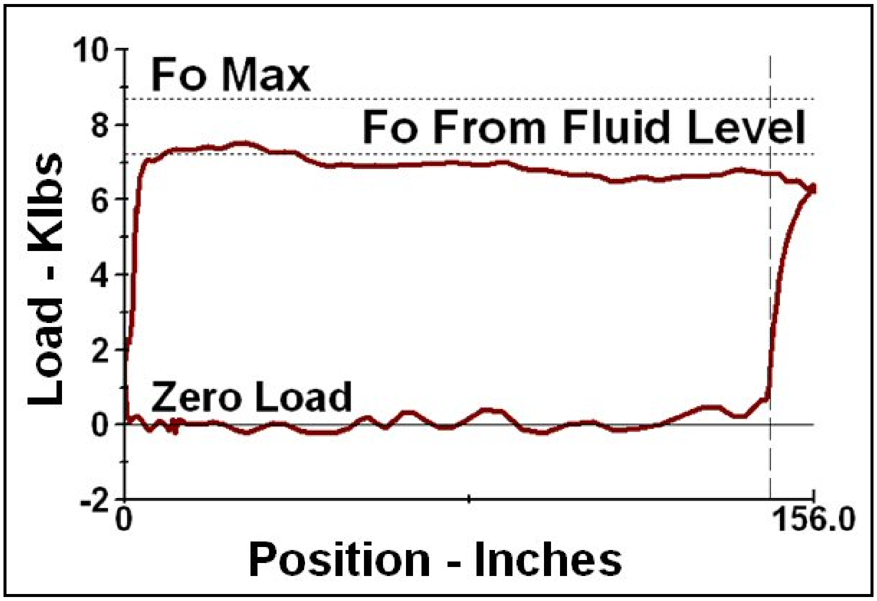

Figure 1 – Normal Pump Card Displaying the Three Reference Load Lines

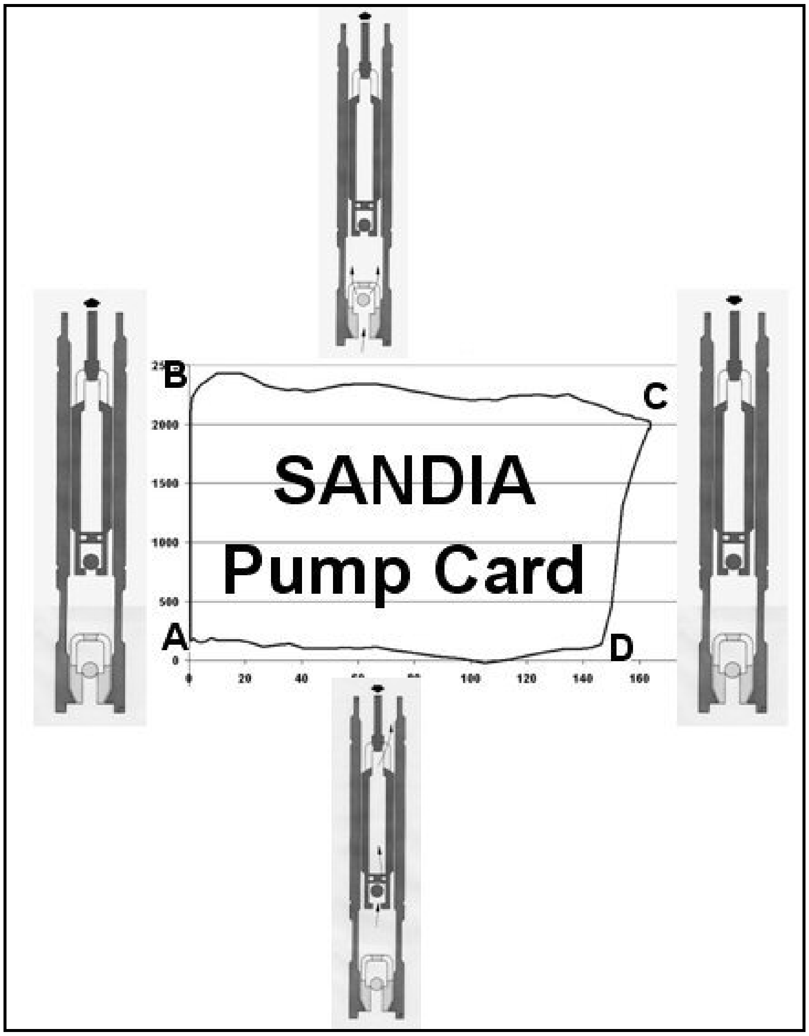

Figure 2 – Pump Card Showing Where Valves Open and Close

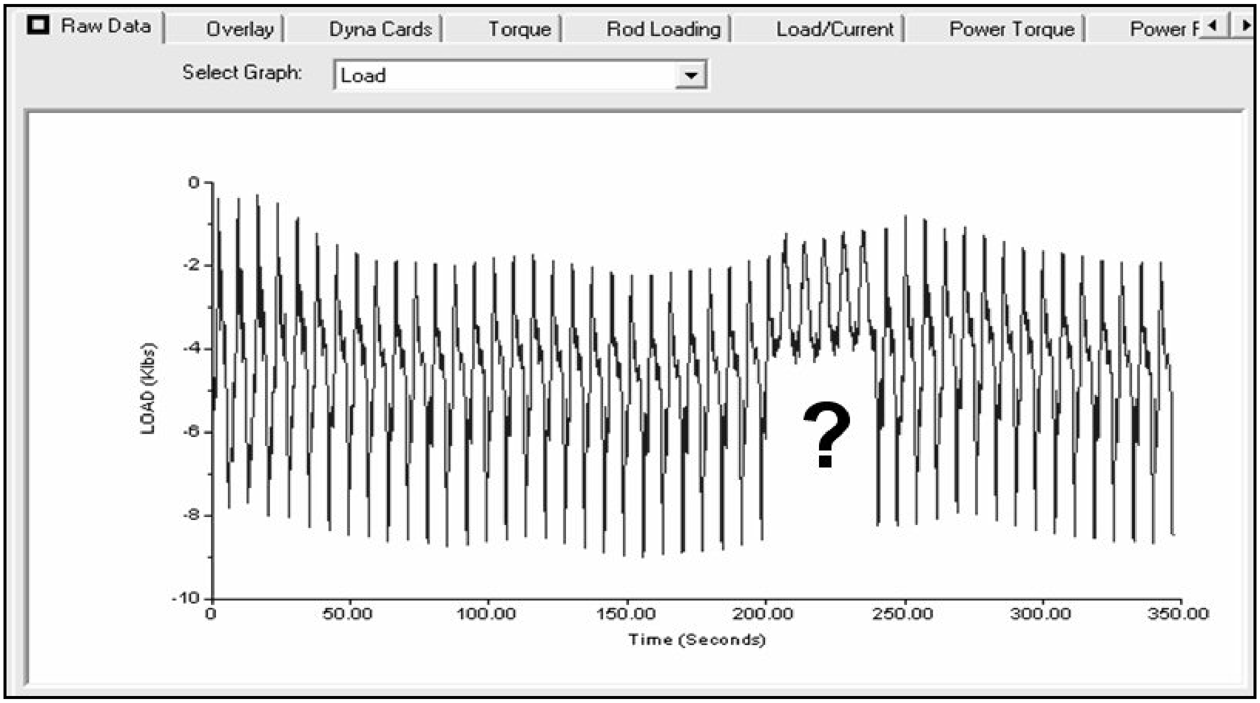

Figure 3 – Standing Valve Sticks Open While Acquiring Dynamometer Data

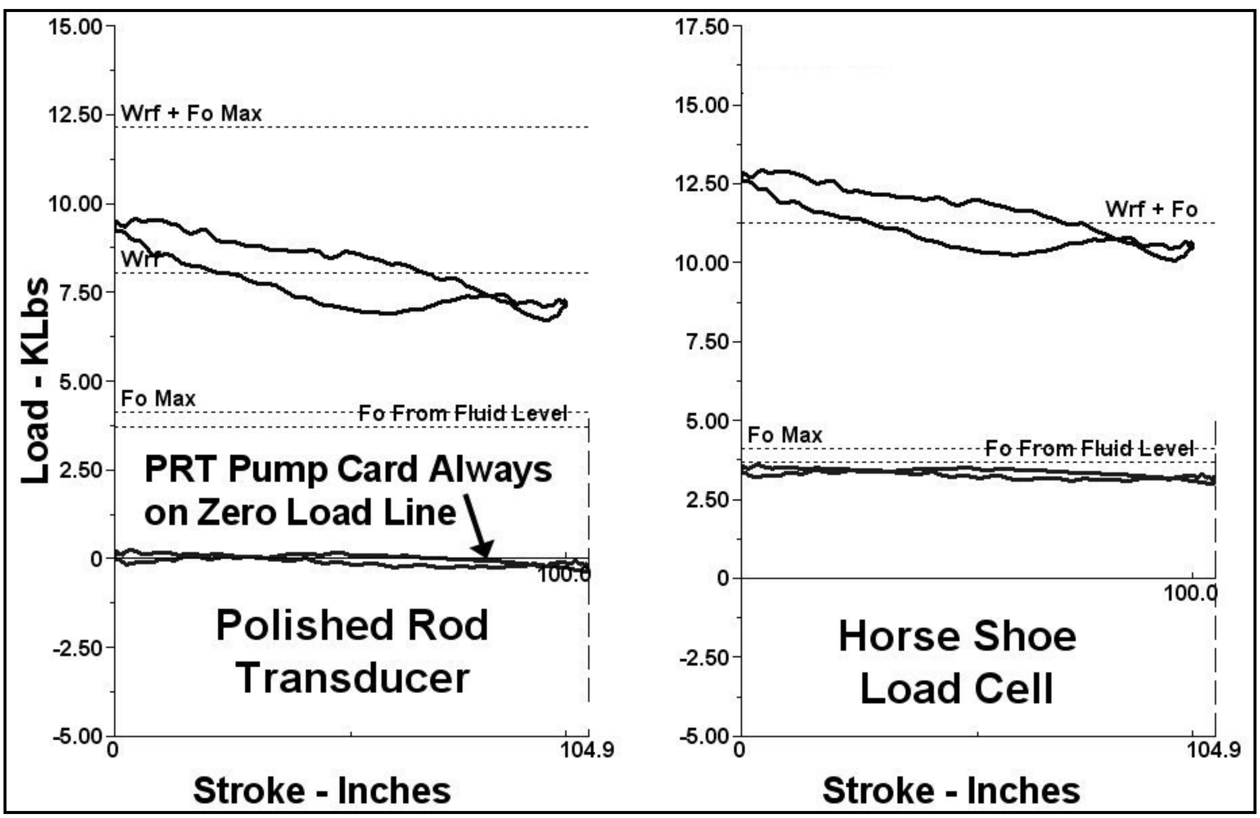

Figure 4 – Type of Dynamometer Impacts Load Value When SV Stuck Open

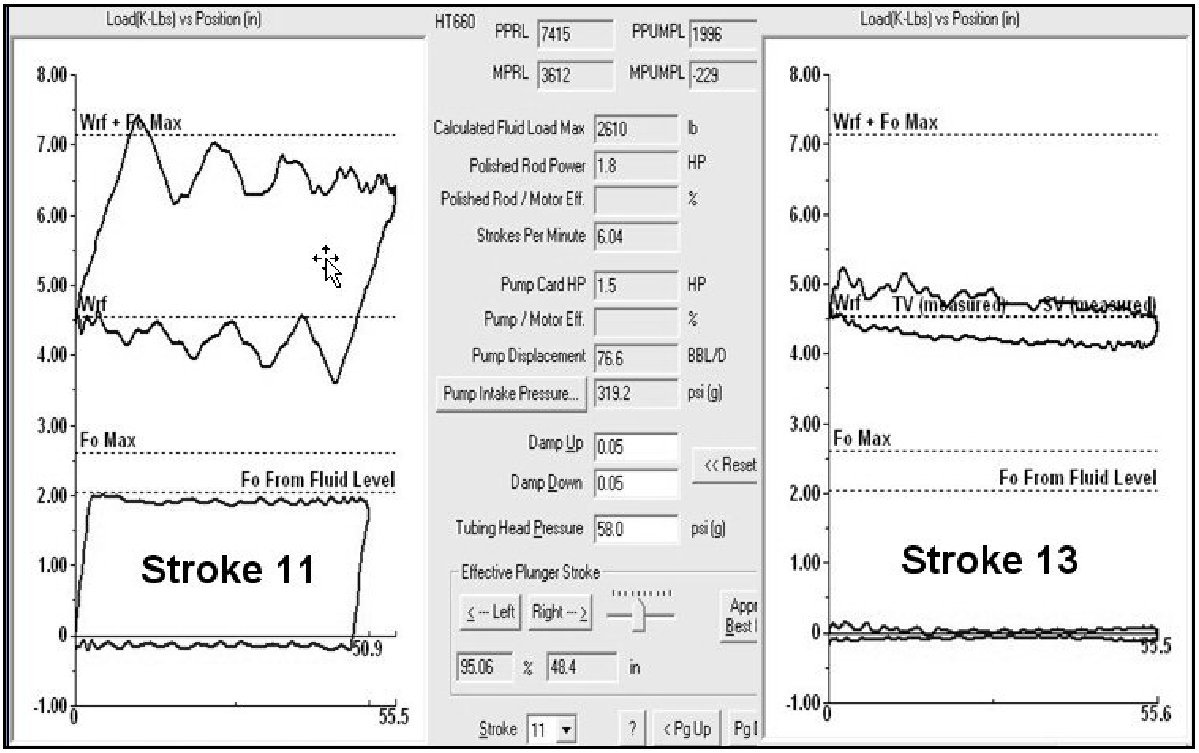

Figure 5 – Traveling Valve Stuck Open

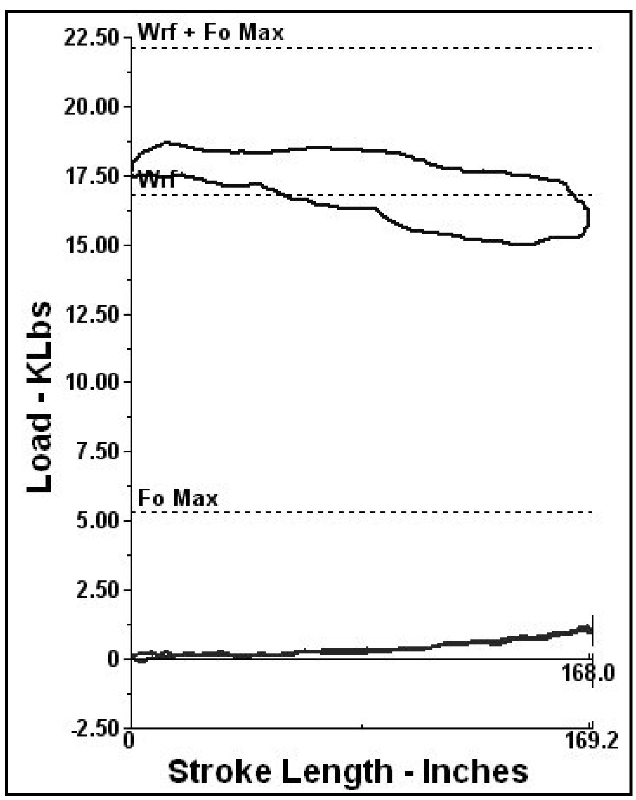

Figure 6 – Deep Rod Part

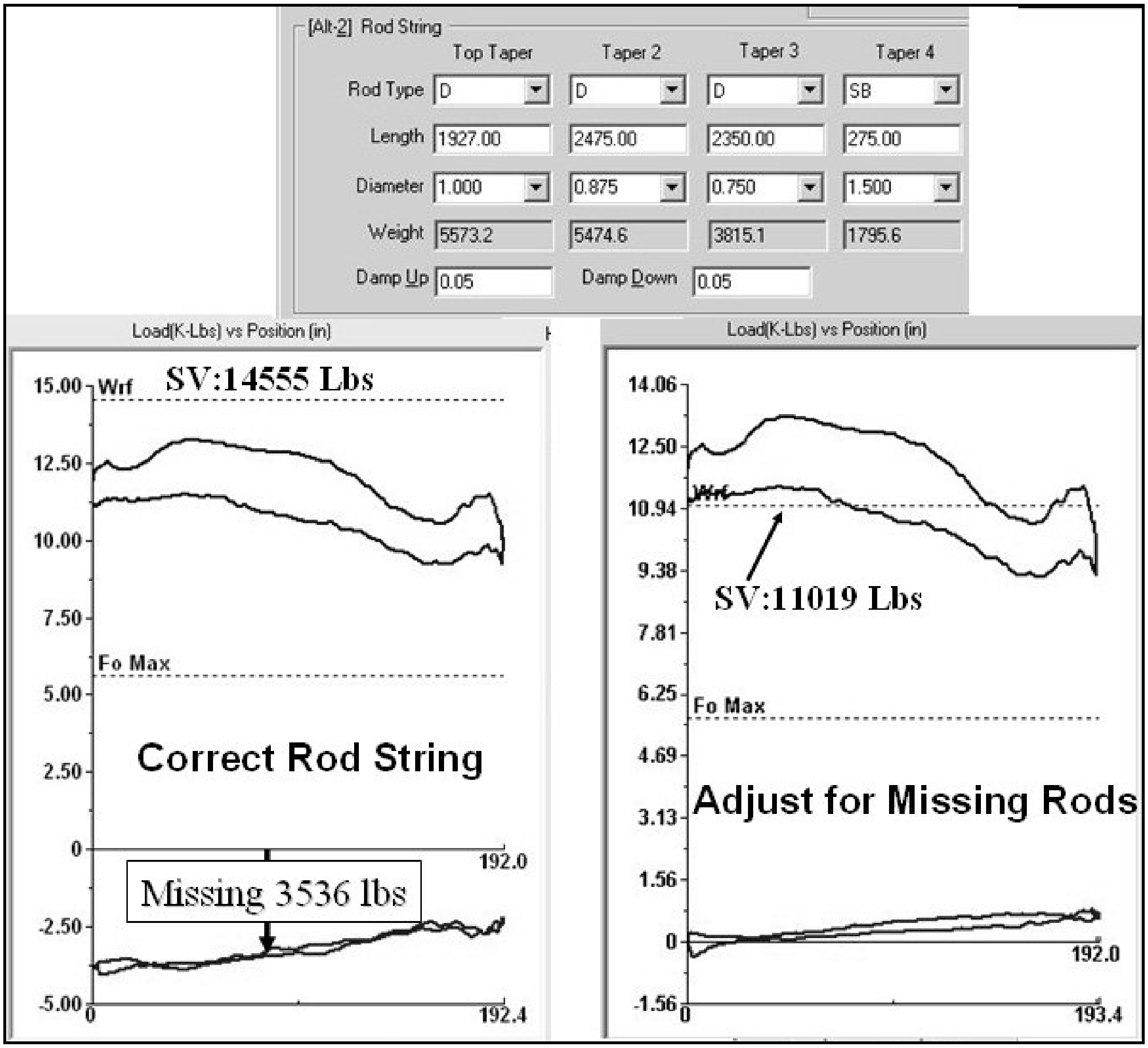

Figure 7 – Shallow Rod Part

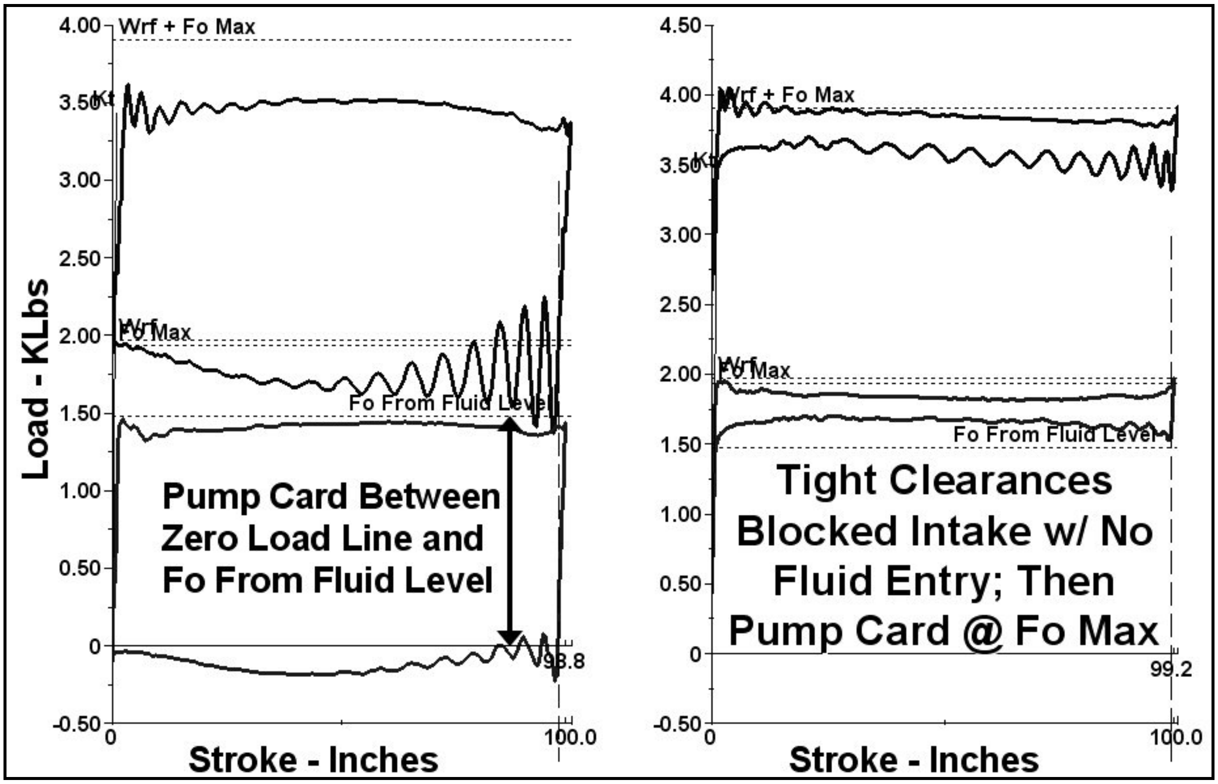

Figure 8 – Flow From Well Blocked From Entering Pump

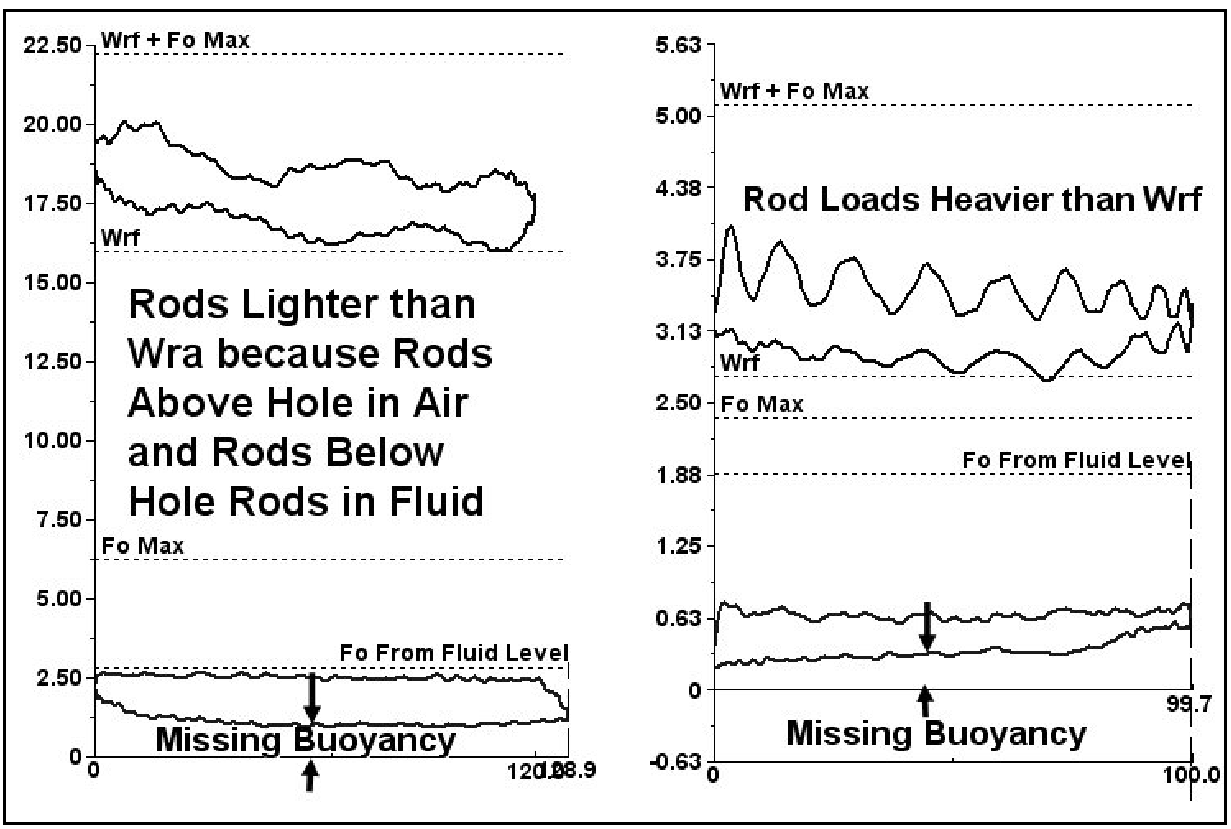

Figure 9 – Missing Buoyancy Force on Rods

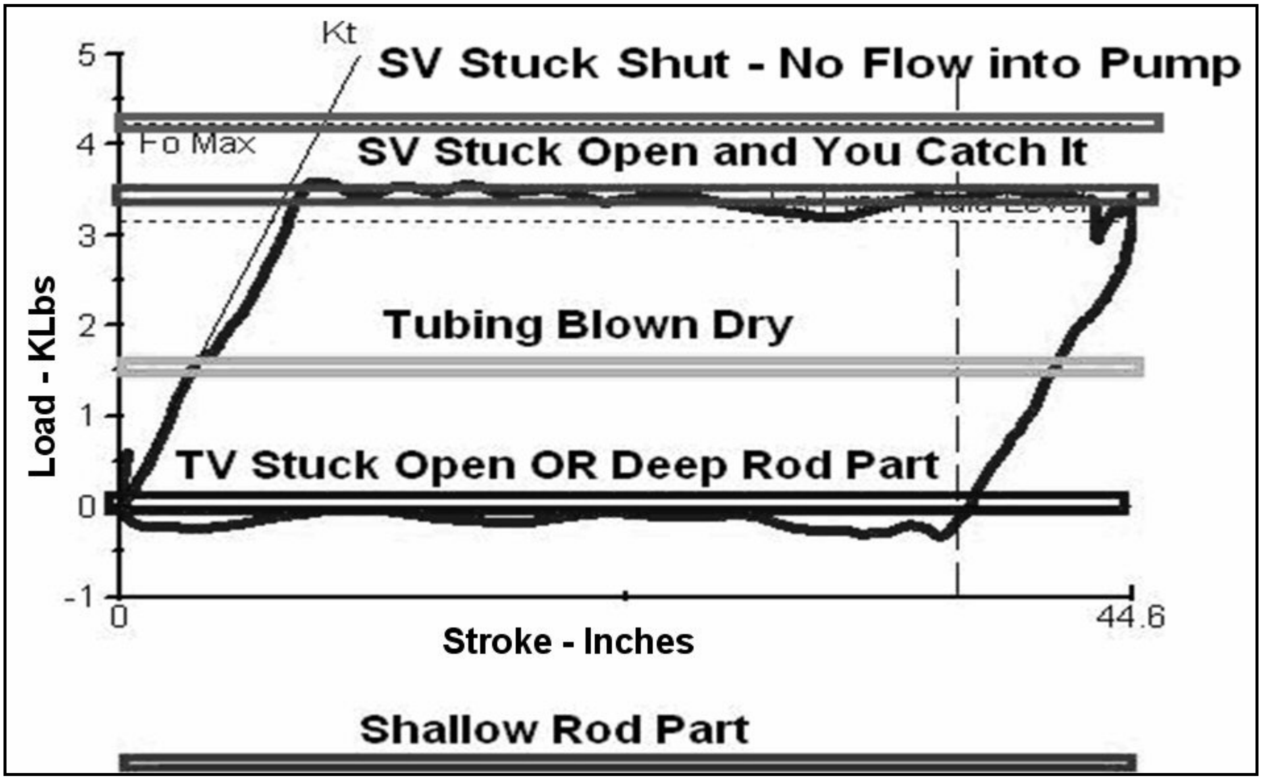

Figure 10 – Pump Card Flat Load Reference Lines